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## Article

# Using Community Detection Analysis to Elucidate Caregivers' Mental Models of Pediatric Concussion Symptoms

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**Abstract:** Due to a culture of resistance around concussion reporting, novel methods are needed to reveal implicit beliefs that could affect symptom reporting. The goal of this study was to elucidate caregivers' mental models of pediatric concussion symptoms using an exploratory community detection analysis (CDA). Caregivers ( $n = 76$ ) of adolescents 10–15 years old participated in a survey that assessed their intentions of seeking medical treatment for 12 injury symptoms following their child's involvement in three hypothetical injury scenarios. We used a series of analyses of variance (ANOVAs) to compare injury symptoms across these scenarios and CDA to determine if caregivers implicitly group symptoms together. We then used logistic regressions to further explore associations between the CDA-identified symptom indices and known factors of injury risk. There were no differences in the likelihood to seek treatment for symptoms across injury scenarios; however, the CDA revealed distinct symptom clusters that were characterized by the degree of risk for non-treatment and symptom type. We observed associations between injury risk factors and intentions of seeking medical treatment for the higher-risk indices. Results indicate that caregivers' mental models of concussion symptoms are nuanced, not monolithic. Therefore, it is inaccurate to measure intentions to seek treatment for concussion without taking these nuances into consideration.

**Keywords:** concussion; clustering analysis; mental models; adolescence; injury; health

## 1. Introduction

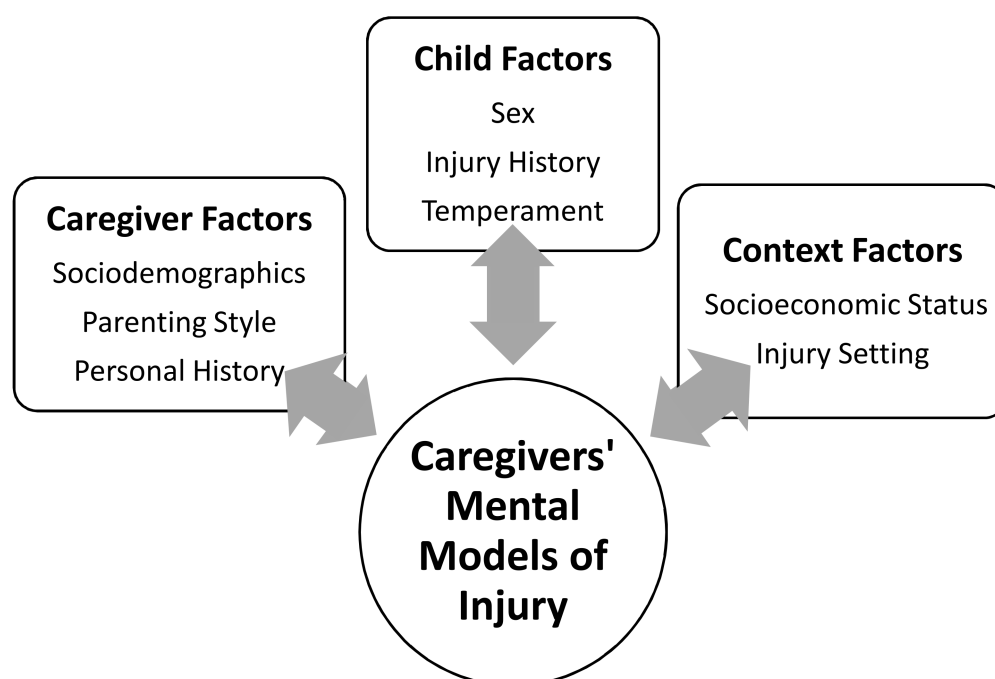
Adolescence is a sensitive time period for brain development, making concussions incurred during this time period especially concerning [1,2]. One estimate suggests that in the U.S. between 2001 and 2005, there were 502,000 emergency department visits for children with concussions; approximately half of these injuries were sports-related [3]. Further, approximately 35% of the overall concussion related visits and 58% of the sports-related concussions were children between the ages of 8 and 13. Another study retrospectively examining data from a pediatric, Level 1 trauma center between 2006–2011 found that the majority of the treated concussion patients were male and that the cause of the concussion varied by age (a shift from fall-related to sports-related injuries as children aged) [4]. Finally, it is estimated that between 2006 and 2013, emergency department visits for pediatric concussions increased by 34.1% [5].

While important, these data are limited in that they are only representative of concussions that result in medical evaluation or treatment. Using emergency room visits or other points of contact with a care provider as an index of concussion rates likely underestimates the prevalence of concussion, as many adolescents and caregivers may not recognize or take symptoms seriously. For example, Register-Mihalik et al. [6] found that the majority of high school athletes in their sample did not

report their concussion symptoms to an adult after a possible concussive injury; a pattern that has been found across various countries and sports [6–9]. Increased knowledge and growing recognition about the consequences of concussion have not counteracted a ‘culture of resistance’ among athletes; athletes resist self-reporting concussion and have poor compliance with concussion management plans [10]. In the context of non-sports injuries, children might be less likely to receive medical treatment as an adult may not be present to observe the injury (e.g., in the context of a fight). In these instances, caregivers may rely on their child’s disclosure and their own observations of changes in the child’s physical, psychological, and cognitive functioning, which further depends on children or their caregivers recognizing and seeking treatment for concussion symptoms. A recent emergency department based survey of adolescents between the ages of 13 and 18 ( $n = 330$ ) and their caregivers ( $n = 391$ ) reported that 41% of the adolescents did not know the causes of concussion, 68.5% of the adolescents did not know the symptoms that would identify a concussion, and 75% would not know what to do if they did recognize concussion symptoms [11]. In this same survey, 48% of caregivers had heard about concussion, 67.5% did not know the symptoms that would be associated with a concussion, 67.8% would not know what to do if they did recognize the symptoms of concussion, and 54% of caregivers did not know the causes of concussion. Thus, understanding how caregivers appraise specific concussion symptoms is critical for informing education and intervention efforts focused on improving post injury management. Accurate and timely knowledge of concussion symptoms is critical for effective diagnosis and management [12], and health care providers cannot treat what they do not know about or what caregivers do not seek treatment for.

### *1.1. Theoretical Frameworks of Injury Prevention*

Researchers have proposed using the “mental models” method of risk communication in the domain of injury prevention [13]. A mental model is a simplified cognitive representation of a dynamic system [14]. For example, Austin and Fischhoff [13] state that in the context of injury prevention, a mental models approach would ask why people fail to see risks, do not make use of protective interventions, or misjudge the effectiveness of protective measures. Once formed, mental models impact the way in which information is processed so that information deemed consistent with existing beliefs is more easily acquired and integrated, strengthening those beliefs regardless of their accuracy. Additionally, when individuals have minimal prior information about a topic, they use the information available to them (e.g., personal experience, advice from peers or family, etc.) to make decisions. Therefore, understanding how caregivers’ mental models related to their child’s injury risks and injury outcomes are formed may lead to improved education and prevention efforts. Specifically, the mental models framework can be applied to: (1) understand what influences caregivers’ intentions to seek medical treatment for their child, and (2) improve concussion outcomes by better aligning caregivers’ and health care professionals’ mental models of pediatric concussion symptom management. Previous researchers suggest that caregivers’ mental models of injuries are likely informed by interactions among child, caregiver, and contextual/environmental factors (see Figure 1). In the following sections, we briefly review these factors and their relationship to childhood injury risks in an effort to highlight ways that child, caregiver, and context factors likely interact to inform caregivers’ mental models of injury. We then leverage this prior foundational research to begin to hypothesize how these factors may also inform caregivers’ mental models of pediatric concussions.



**Figure 1.** Examples of factors that may influence caregivers’ mental models of injury.

#### 1.1.1. Factors Associated with Childhood Injury Risk

Child factors associated with an increased risk for unintentional injury include the child’s sex, personality /temperament, and injury history. Typically, boys are at an increased risk for unintentional injuries compared to girls [15]. Similarly, diagnoses that are more common among males (see Rosen and Peterson [16]) including Attention Deficit Hyperactive Disorder (ADHD), learning disabilities, and personality traits like impulsivity and aggression are related to an increased risk of unintentional injury [16–23]. Further, children with these traits seem to be more prone to injuries in general [20–22]. A history of injuries is associated with an increased risk for future injuries potentially because of these child-specific individual difference factors [24–26].

Caregiver personality, parenting styles, and personal experience with specific injuries are also associated with childhood injury risks. Caregivers with lower levels of self-reported coping abilities have children with a higher risk of injuries [27], and caregivers who report themselves as more conscientious, protective, worried about safety, confident in their ability to keep their child safe, and in control over their child’s health have children who engage in less risk-taking behavior and have fewer injuries [28]. There are also associations between caregivers’ parenting style and a child’s injury risk. For example, in Morrongiello et al. [29], children of caregivers who had a permissive parenting style had an increased risk of a medically-attended injury, which the researchers attributed to the pattern of permissive caregivers using fewer rules. Parenting style, depression, and beliefs about locus of control have also been related to styles of parenting supervision, which have been found to be directly related to child injury risk [30–32]. Caregivers that report being vigilant in their supervising practices have children with a lower risk of sustaining injuries, and children of caregivers who practice strong physical supervision behaviors (i.e., being close in proximity to the child) have been found to engage in fewer risk-taking behaviors [28]. Additionally, and largely related to this study, a large birth cohort study ( $n = 1265$ ) found that the child’s sex (being male), adverse life events (more than four), and the caregivers’ parenting style (high maternal punitiveness) were related to an increased risk for traumatic brain injury [33].

Contextual factors are also associated with childhood injury risk. Family poverty is associated with higher rates of child injuries requiring medical attention [34,35], and lack of social support for caregivers

is associated with less safe homes for children [32]. Higher levels of caregiver stress has also been related to more injuries experienced in late childhood [36]. As described earlier, children participate in fewer risky behaviors when an adult is in close physical proximity, or when adults practice strong physical supervision. In sports settings, there is almost always an adult present and supervising children, often times in multiple roles (e.g., referees, lifeguards, coaches, trainers, etc.). However, in non-sports settings, there may not be an adult nearby to limit risky behaviors, resulting in children and teenagers being at an increased risk for both sustaining an injury and also not receiving the appropriate medical attention for that injury. Conversely, sports safety gear, like padding and helmets worn in football and hockey, has been related to children participating in more risky behaviors that result in injuries [37].

### 1.1.2. Applying these Factors to Understand Caregivers' Mental Models

These child, caregiver, and contextual factors likely influence how caregivers will respond to their child's injuries, or the caregivers' mental models of pediatric concussion. For example, Morrongiello and Hogg [38] reported that after an injury, mothers were more concerned about injuries to their daughters than injuries to their sons [38]. Also in this study, mothers believed that active injury-prevention strategies could potentially prevent subsequent injuries in daughters, but did not believe that these strategies would prevent future injuries in sons. The researchers posited that mothers may expect more risky behaviors in sons than daughters, have more concern for their daughters' injuries than their sons, and perceive a stronger ability to prevent more injuries in their daughters than their sons. Collectively, these data suggest that caregivers may view daughters as less physically resilient or more susceptible to long-term consequences of injuries than their sons, or that son's risk-taking is inevitable (i.e., "boys will be boys"). Explanations for these differences in caregiver mental models of injury could be derived from cultural views of gender, however another explanation may be that caregivers may become desensitized to injuries or threats as their child obtains and recovers from them. This is supported by caregivers having less concern for injuries sustained by their boys, even though boys seem to obtain more injuries.

Several studies have attempted to understand how these factors may contribute to a child's risk of sustaining a concussion and how specific factors are related to caregivers' attitudes towards concussion reporting and management. For example, Kroshus et al. [39] found that caregivers of children who had previously been diagnosed with a concussion and who perceived that their child had a greater chance of sustaining a concussion were more likely to communicate with their child about reporting concussion symptoms [39]. Also, caregivers with higher income and education levels have been found to have more knowledge about concussions and safer attitudes related to concussion management [40]. Additionally, McNally et al. [41] found that caregiver distress was associated with reporting a higher number of symptoms [41].

While these studies are informative, there is a lack of research on risk factors associated with pediatric concussions utilizing a mental models framework. The current study fills this gap and provides a new approach that can assist researchers and clinicians towards developing education and prevention efforts. For example, counter to overall injury risks, females are more frequently diagnosed with concussions in both sports and non-sports contexts and report poorer post-concussion outcomes than males [42–44]. Many theories have been proposed to explain why girls have higher rates of diagnosed concussion injuries, including physiological ones like girls having greater ball-to-head ratios and weaker neck muscles [45]. However, using a caregivers' mental models of injury lens, we may also conclude that caregivers may be assessing their girls' injuries as more serious than their boys' injuries. This could result in caregivers seeking out medical treatment for their girls, but not their boys, which may reflect a reporting/treatment bias. Thus, understanding caregivers' mental models of pediatric concussions may result in a better understanding of who is at risk for not receiving or taking concussions seriously, as well as more efficient and better-targeted education and intervention efforts.

## 1.2. The Current Study

In order to provide initial insight into caregivers' mental models of concussion in adolescence, we performed an exploratory analysis on caregivers' self-reported intentions to seek medical treatment for 12 symptoms sustained from three hypothetical scenarios involving their child: a fight, a fall, and while playing sports. Previous applications of the mental models approach in the injury prevention field have focused on methods used to extract explicit or overt beliefs [13], but in this study, we used methods to assess caregivers' implicit beliefs. This approach overcomes concerns about social desirability effects and does not require participants to be self-aware of how they think or group concussion symptoms together. After comparing caregivers' intentions across injury scenarios, we conducted a Euclidean-distance based community detection analysis (CDA) using caregivers' intentions to seek medical treatment for different concussion symptoms. We then examined whether child and caregiver risk factors influenced intention to seek care for each identified symptom cluster. Previous research has begun to cluster and evaluate concussion symptoms separately from one another, however most have focused on which symptoms appear concurrently at diagnosis, symptom type, or awareness of that symptom being related to concussion [46–49] and not on intentions to seek treatment. While informative, clustering symptoms at or post-diagnosis may limit educational efforts by not capturing symptom profiles that caregivers believe to be less serious or in need of treatment; our approach of clustering symptoms by caregivers' intent to seek treatment pre-injury overcomes this limitation. A previous study clustered specific concussion symptoms by intent to seek treatment using the Theory of Planned Behavior, however it was limited in that it focused on adult hockey players [50]. The current study expands on this previous study by examining caregivers' intentions to seek treatment for specific symptoms experienced by their early-adolescent aged child (10–15 years old) in both sports and non-sports settings.

## 2. Materials and Methods

### 2.1. Participants

We conducted a survey study with a convenience sample of caregivers of at least one child between the ages of 10 and 15. Participants were instructed to answer the questions based on their youngest adolescent within the age range. This range was chosen because caregiver management of concussion symptoms in early adolescence is understudied in comparison to older adolescence and young adulthood. Participants were contacted by the University of Alabama at Birmingham (UAB) Survey Research Unit (SRU) using phone records; 76 caregivers met eligibility criteria and completed the interview. Data on non-eligible participants and participants who refused were not collected.

### 2.2. Survey

The survey consisted of 36 items drawn from the Rosenbaum Concussion Knowledge and Attitudes Survey—Student Version (RoCKAS-ST [22]). Caregivers reported on the likelihood that they would bring their child to a doctor, nurse, or athletic trainer if their child was exhibiting specific symptoms after hitting his or her head in three distinct scenarios: while playing sports, during a physical fight, and because of a fall. A sample question was “Imagine your child had a headache within 1 to 2 days after hitting his head while playing sports; would you take your child to see a doctor, nurse, or athletic trainer based on that one symptom?” Participants answered the questions using a 1 to 4 scale: (1) “definitely would not”, (2) “probably would not”, (3) “probably would”, and (4) “definitely would”. Caregivers were told that the symptom manifested after their child hit his or her head, but the word ‘concussion’ was not used in the prompts. Caregivers' intention to seek medical treatment was measured as research suggests that intentions are good predictors of future behavior [51,52]. The concussive symptoms included in the survey were: headache; neck pain; blurred vision; a visible cut, bump, or bruise; light and noise sensitivity; difficulty concentrating;



feeling sleepier than usual; trouble falling or staying asleep; feeling more irritable and emotional; feeling dizzy; loss of consciousness; and vomiting.

The survey also contained items on sociodemographic characteristics and the child's history of injury, participation in sports, and play preference (i.e., the type of "play" the child often participates in). Sociodemographics included caregiver and child sex and age, caregiver's race/ethnicity, caregiver's marital status, and caregiver's highest level of completed education. Injury history was measured by caregivers' "yes" or "no" responses to the prompt: "Has your child ever been treated for a sprain or broken bone?" The child's play preference was measured by caregivers' responses to the prompt: "Does your child like rough and tumble play? By this I mean wrestling, tackling, or play-fighting with others." Possible answer choices included: (1) "Yes, my child likes this kind of play," (2) "Somewhat, my child will play like this sometimes," and (3) "No, my child does not like to play this way." This prompt was used to determine if the caregivers' perception of their child's temperament during play influenced caregivers' decisions to seek treatment for injury symptoms. After completing the survey participants were offered educational information and were thanked for their time. The study protocol was approved by the Institutional Review Board of UAB.

### 2.3. Analytic Approach

First, a series of ANOVAs were conducted to determine if there were differences in caregivers' intentions to seek medical care by context (e.g., strength of intention to seek medical treatment for blurred vision after a fight, after a sports injury, and after a fall). We asked about each symptom across these contexts in an attempt to see if caregivers view the seriousness of symptoms differently if they are incurred in different contexts. After correcting for multiple comparisons using the false discovery rate (FDR) procedure [53], we did not find significant differences across contexts for any symptom ( $p > 0.05$  for all comparisons); therefore, an overall symptom-based intention index was created by averaging caregivers' reports across contexts (e.g., strength of intention to seek medical treatment scores after a fight, after a sports injury, and after a fall if the child lost consciousness were averaged into one 'intention index score' for loss of consciousness).

These symptom-based averaged scores were used in an exploratory Euclidean distance-based CDA to determine if symptoms cluster into specific communities based on caregivers' likelihood of seeking medical treatment. The clusters were compared using a nonparametric independent samples Kruskal-Wallis test to examine differences in intention to seek medical treatment across cluster assignments [54].

#### 2.3.1. Community Detection Analysis

Community detection is a statistical approach grounded in graph theory that applies mathematical constraints to uncover the community structure within a dataset. The Girvan-Newman community detection algorithm relies on the edge-betweenness centrality metric to identify the underlying community structure [55,56]. Relying on the efficiency principle that information will tend to travel over the shortest path, betweenness centrality examines the influence of a given edge by counting the number of short paths connecting other nodes that run along the examined edge. The edges with the highest edge betweenness are then progressively removed from the network and the consequences of their removal are quantified by recalculating the betweenness centrality of the remaining edges. The edges with the highest betweenness centrality are likely those edges that connect distant communities, as the number of edges available to travel along are sparse, resulting in a higher number of connections. When these edges are removed, only the identified communities remain. This algorithm has been shown to accurately recover the community structure in simulated networks [56] and has been applied to varied data types ranging from neuropsychological measures [57,58] to functional brain networks [59]. It has not yet been applied to uncover implicit mental models of injury symptoms and the current analysis provides a critical proof of concept evaluation for using the CDA approach.

The average responses across each injury context were configured into a participant-by-symptom matrix. Briefly, the algorithm calculated the Euclidean distance between each of the symptoms based on the pattern of participant responses with higher values indicating greater distance between symptoms in Euclidean space. An adjacency matrix was then created by applying a threshold to the matrix of Euclidean distance values such that a '1' indicated a connection between symptoms and a '0' indicated no connection. This threshold was set to ensure that no symptoms had no connections (e.g., every symptom had at least one '1' in the adjacency matrix). The threshold applied in the current analysis was 2.41. After establishing these connections, the edge betweenness was calculated for each edge, and the edges with the highest betweenness centrality were removed until no more edges remained in the network and the community structure was identified. Analyses were conducted using R [60] and SPSS (V.24).

### 2.3.2. Comparing Clusters Across Sociodemographics, Injury History, and Play Preference

The CDA determined that caregivers' mental models of concussion symptoms are not monolithic, but are instead nuanced. We found that symptoms cluster together by perceived severity and intent to seek treatment. Therefore, it is inaccurate to group or to measure intentions to seek treatment for concussion without taking these nuances into consideration methodologically. Thus, we created three indices based on the CDA and conducted logistic regressions to examine if individual differences in child and caregiver factors predicted caregivers' intention to seek treatment within each of the three symptom clusters. We also conducted a logistic regression using the average of all of the symptoms' intention to seek treatment scores.

Child factors included in the models were gender, age, history of injury, and play preference. Caregiver factors included race, marital status, and education. The first models we conducted revealed significant Hosmer-Lemeshow goodness of fit tests ( $p < 0.05$ ), therefore, to improve model fit, we removed race and marital status from the final models. Education was kept as a variable in the model because of its strong relation with caregiver concussion awareness and attitudes in previous literature. This resulted in non-significant Hosmer-Lemeshow tests ( $p > 0.05$ ). The child's participation in sports was also not included in these analyses, as only four participants reported that their child was not involved in some sort of sport. Odds ratios were estimated to determine the relationship between caregiver intention to seek medical treatment and the predictors in the models. The data were skewed such that for most symptoms, most caregivers had strong intentions of seeking treatment for their child (scores of "probably" or "definitely" would seek treatment), so for the logistic regression analyses, the data were recoded so that answers of "definitely would not", "probably would not", and "probably would" seek treatment for that symptom were "at-risk for not seeking treatment", while answers of "definitely would" seek treatment for that symptom were "likely to seek treatment".

## 3. Results

On average, the survey took 19 min to complete. The respondents were ages 28–58 ( $M = 43.67$ ,  $SD = 6.7$ ) and had children aged between 10–15 years ( $M = 12.15$ ,  $SD = 1.76$ , Table 1). Respondents were primarily married (75%), white (79%), and female (70%).

Initially, intentions to seek medical treatment for a headache differed by context ( $p = 0.01$ ), however after correcting for multiple comparisons using the FDR procedure, this relationship did not reach statistical significance. No other symptom-by-context differences were observed (Table 2). Therefore, as previously described, we collapsed responses across contexts by creating an average intention score for each symptom.



**Table 1.** Child and caregiver demographic ( $n = 75$  caregivers).

Variable	Levels of Variable	Total	%
Child Gender	Male	43	57
	Female	33	43
Child Age (years)	10	6	7
	11	15	20
	12	16	21
	13	9	12
	14	15	20
	15	15	20
Caregiver Gender	Male	20	26
	Female	53	70
	Unknown	3	4
Caregiver Age	26–30	4	5
	31–35	6	8
	36–40	12	16
	41–45	21	28
	46–50	25	33
	51–55	5	7
	56–60	3	4
Ethnicity (Caregiver)	White	60	79
	African American	13	17
	Native American	1	1
	Other	2	3
Marital Status	Never Married	6	8
	Divorced	8	11
	Widow	3	4
	Married	57	75
	Domestic Partnership	1	1
	Refused	1	1
Caregiver's Education Level	Some High School	1	1
	High School	10	13
	GED	1	1
	Some College	6	8
	Associates	14	18
	4-year Degree	27	36
Insurance	Masters/Doctorate	17	22
	CHIP *	1	1
	Medicaid	12	16
	Private/Employer Provided	60	79
	Other	3	4

Note: Percentages were rounded to the nearest whole number.

\* CHIP = Children's Health Insurance Program.

**Table 2.** Average intention to seek medical treatment score by symptom.

Symptom	Sport Mean (SD)	Fight Mean (SD)	Fall Mean (SD)	Across Context Mean (SD)	<i>p</i>
Headache	2.75 (0.90)	2.83 (0.95)	3.16 (0.82)	2.91 (0.70)	0.01
Neck Pain	3.07 (0.85)	2.95 (0.86)	3.21 (0.72)	3.10 (0.72)	0.14
Blurred Vision	3.79 (0.44)	3.78 (0.45)	3.82 (0.42)	3.80 (0.40)	0.85
Bruise, Bump, Laceration	2.84 (0.97)	2.95 (0.90)	2.95 (0.93)	2.90 (0.88)	0.72
Sensitivity to Light and Noise	3.56 (0.66)	3.63 (0.59)	3.55 (0.68)	3.60 (0.59)	0.71
Difficulty Concentrating	3.42 (0.70)	3.36 (0.72)	3.48 (0.67)	3.43 (0.65)	0.58
Feeling Sleepier	3.35 (0.81)	3.36 (0.83)	3.42 (0.81)	3.37 (0.80)	0.87
Difficulty Falling/Staying Asleep	2.92 (0.96)	2.86 (0.97)	2.95 (0.92)	2.91 (0.93)	0.83
Increased Irritability/More Emotional	2.62 (0.86)	2.62 (0.91)	2.68 (0.91)	2.62 (0.87)	0.87
Dizziness	3.64 (0.65)	3.60 (0.66)	3.65 (0.60)	3.64 (0.54)	0.87
Vomiting	3.53 (0.66)	3.49 (0.68)	3.54 (0.68)	3.53 (0.60)	0.97
Loss of Consciousness	3.92 (0.39)	3.94 (0.38)	3.94 (0.38)	3.96 (0.17)	0.90

Note: *p*-values were derived from ANOVAs. Response choices were on a scale of 1–4, with 1 being “definitely would NOT seek medical care” and 4 being “definitely would seek medical care”. Each caregiver responded to each symptom across three contexts (after a fight, after playing sports, and after a fall) which were averaged to compute the reported results. After multiple comparison procedures, no symptoms were statistically significant across context. One participant qualified as an outlier based on low likelihood to seek treatment, so the analyses were re-analyzed excluding this participant’s responses. This greatly reduced the standard deviation of the variables without changing the overall pattern of results or their significance. Therefore, the outlier was excluded from analyses.

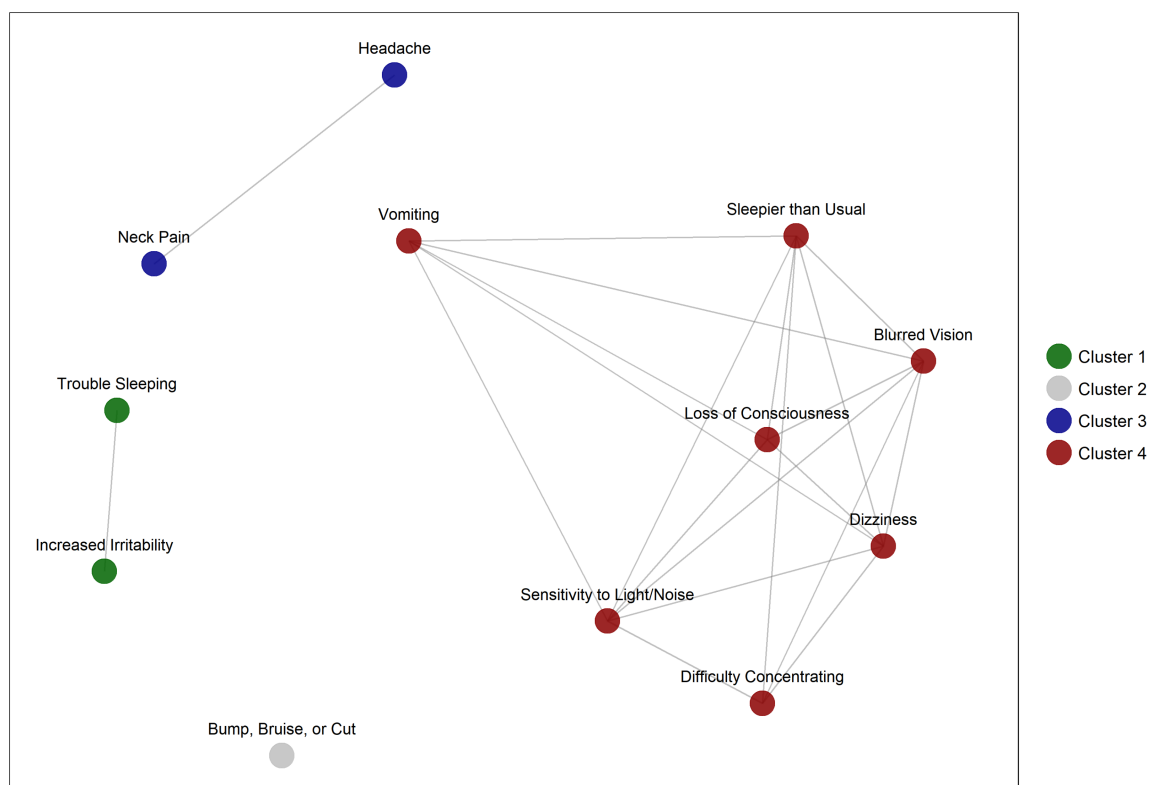
### 3.1. Community Detection Analysis Results

Four clusters were identified using the community detection algorithm (Figure 2, Table 3). The first cluster contained two symptoms, difficulty falling or staying asleep and feeling more irritable or emotional. The second cluster only contained the bruise-bump-cut symptom and was therefore considered an outlier cluster given its isolation from the other symptoms included in the analysis. The third cluster contained two symptoms, headache and neck pain. The fourth cluster was the largest cluster and contained seven symptoms: blurred vision, sensitivity to light or noise, difficulty concentrating, feeling sleepier than usual, dizziness, loss of consciousness, and vomiting.

**Table 3.** Cluster assignments, median intention scores, and IQR (interquartile range).

Symptom	Cluster Assignment	Median	IQR (50%)
Increased Irritability/More Emotional	1	2.0	2.0–3.3
Trouble Falling/Staying Asleep	1	3.0	2.0–4.0
Bruise, Bump, Cut	2	3.0	2.0–4.0
Headache	3	3.0	2.3–3.5
Neck Pain	3	3.0	2.3–3.6
Difficulty Concentrating	4	3.7	3.0–4.0
Feeling Sleepier	4	4.0	3.0–4.0
Vomiting	4	4.0	3.0–4.0
Sensitivity to Light/Noise	4	4.0	3.0–4.0
Feeling Dizzy	4	4.0	3.0–4.0
Blurred Vision	4	4.0	4.0–4.0
Loss of Consciousness	4	4.0	4.0–4.0

Note: Clusters significantly differed on intention to seek medical treatment ( $p = 0.036$ ). Means for each cluster were: Cluster 1: 2.8; Cluster 2: 2.9; Cluster 3: 3.0; Cluster 4: 3.6.



**Figure 2.** Clusters derived from community detection analysis. The clusters with each symptom's mean intention score were: Cluster 1: Increased Irritability/More Emotional (2.6), Trouble Falling or Staying Asleep (2.9); Cluster 2: Bruise-Bump-Cut (2.9); Cluster 3: Headache (2.9), Neck Pain (3.1); Cluster 4: Difficulty Concentrating (3.4), Feeling Sleepier (3.4), Vomiting (3.5), Sensitivity to Light/Noise (3.6), Feeling Dizzy (3.6), Blurred Vision (3.8), Loss of Consciousness (4.0).

The cluster means of caregivers' intention to seek medical treatment were compared using the independent-samples Kruskal-Wallis Test. The results suggest that the mean intention to seek treatment scores differed by cluster type ( $p = 0.036$ ). Conceptually, we used these clusters to create three indices based on the symptoms clustered and their perceived severity. Index 1, or "higher risk-nonspecific cognitive symptoms", included trouble falling or staying asleep and increased irritability/feeling more emotional. We used the term "higher risk" to denote a higher risk of not seeking care and the term "nonspecific" to reflect that these symptoms are not necessarily attributed to concussions. Cluster 2 only contained the symptom visible bruise, bump, or cut and Cluster 3 contained headache and neck pain. Although bruise, bump, or cut did not cluster with the other two symptoms based on Euclidean distance, the mean score for bruise, bump, or cut was the same as headache (2.9), and the clusters were not significantly different from each other when directly compared. Therefore, for conceptual reasons we identify both of these clusters as being in the "higher risk-nonspecific physical symptoms" index. Finally, the fourth cluster contained symptoms that were all very likely to result in medical treatment, including difficulty concentrating, feeling sleepier, sensitivity to light/noise, blurred vision, feeling dizzy, vomiting, and loss of consciousness. Therefore, we identify this index as the 'lower risk-cognitive/perceptual symptoms.'

### 3.2. Logistic Regression Results

The adjusted odds ratios for each logistic regression model are presented in Table 4. Child injury history (previous treatment for a sprain or a broken bone) was associated with caregivers' intentions to seek medical treatment for both the higher risk-nonspecific cognitive and higher risk-nonspecific physical indices. In both cases, prior medical treatment for a sprain or a broken bone decreased

caregivers' intentions of seeking medical treatment for that index of symptoms. None of the variables were significantly associated with caregivers' average intentions to seek treatment scores or intentions to seek treatment for the lower-risk cognitive perceptual index.

**Table 4.** Adjusted odds ratios for logistic regression models for caregivers' intent to seek treatment for concussion symptoms.

Variables Included in Each Model	aOR (Adjusted Odds Ratio)	95% CI	p
Model: All symptoms			
Higher Education	0.90	0.42, 1.96	0.79
Male Child	2.10	0.51, 8.68	0.31
Previous Treatment for Sprain/Broken Bone	0.43	0.13, 1.38	0.16
Child Liking Rough and Tumble Play	1.48	0.71, 3.11	0.30
Model: Higher Risk-Nonspecific Cognitive Symptoms			
Higher Education	0.92	0.47, 1.78	0.80
Male Child	1.46	0.38, 5.52	0.58
Previous Treatment for Sprain/Broken Bone	0.25	0.08, 0.77	0.02 *
Child Liking Rough and Tumble Play	1.28	0.66, 2.48	0.46
Model: Higher Risk-Nonspecific Physical Symptoms			
Higher Education	0.61	0.30, 1.25	0.18
Male Child	1.44	0.38, 5.40	0.59
Previous Treatment for Sprain/Broken Bone	0.16	0.05, 0.53	0.00*
Child Liking Rough and Tumble Play	0.97	0.50, 1.88	0.94
Model: Lower Risk-Cognitive Perceptual Symptoms			
Higher Education	0.40	0.07, 2.15	0.29
Male Child	0.19	0.01, 3.79	0.27
Previous Treatment for Sprain/Broken Bone	0.40	0.03, 4.97	0.48
Child Liking Rough and Tumble Play	2.18	0.49, 9.65	0.30

Note: Higher risk-nonspecific cognitive symptoms index: feeling more irritable/emotional, and difficulty falling/staying asleep; Higher risk-nonspecific physical symptoms index: headache, neck pain, and bruise/bump/laceration; Lower risk-cognitive perceptual symptoms index: light/noise sensitivity, dizziness, loss of consciousness, vomiting, blurred vision, difficulty concentrating, and feeling sleepier than usual. \* indicates significance in the model.

#### 4. Discussion

We used community detection analysis (CDA) to reveal caregivers' implicit mental models of concussion symptoms. Caregivers' intention to seek medical treatment for their child varied by symptom and cluster type, but not by injury scenario. Four symptom clusters were identified, which varied based on two factors: the type of symptoms in that cluster and their perceived severity. Using this framework, indices were conceptually classified by risk level and by group, with higher risk for not receiving treatment being indicated by mean cluster scores less than '3' (or a mean score less than 'probably would' seek treatment).

In the context of a mental models approach, these findings suggest that caregivers view concussion symptoms with varying degrees of seriousness and need for medical treatment and implicitly group symptoms together. Previous research has suggested that although caregivers are generally knowledgeable about concussion, in comparison to physical symptoms, they are less knowledgeable about mental-health related symptoms [61–64]. Our results extend this finding by suggesting that there are some 'nonspecific' symptoms (or symptoms that could be mistaken for another etiology and not associated with concussion, such as a headache and dehydration [65]) that caregivers viewed as less serious than other mental health symptoms (e.g., difficulty concentrating). Additional research is needed to determine the processes by which mental models of concussion symptoms are created.

#### 4.1. Practical Applications

Additionally, our CDA approach can be used to develop more effective interventions designed to promote awareness of concussion symptoms, including post-injury care programs intended to promote adherence to care plans. The majority of primary prevention programs designed to promote awareness of concussion symptoms are designed without first assessing the target population's mental models of concussion. This emic (layperson, insider) vs. etic (expert, outsider) disconnect can create a situation where professionals and caregivers are talking past one another. Interventions might be more successful if they are well matched to caregivers' mental models of concussion, which might vary by population. Since frameworks of mental models stipulate that these implicit models impact the way in which future information is processed such that information deemed consistent with existing beliefs is more easily acquired and integrated, understanding caregivers' mental models of concussion could drastically improve adherence to post-concussive management plans and overall awareness of concussion injuries.

For example, some adolescents may be at-risk for non-treatment if they are relying on their caregivers to alert medical professionals to potential injury symptoms. Research suggests that caregivers often underreport or underestimate their child's symptom severity when it comes to injury [66,67], and prefer coaches or medical staff to identify and make decisions about athlete's injuries, suggesting that caregivers are not confident at making injury assessments for their child [68]. This can become problematic, as less approachable or untrained coaches and medical staff can impede timely and accurate reporting of injury symptoms [65]. Risk for non-reporting may be increased if the child or adolescent is injured in sports or non-sport settings without a caregiver or another adult present. Collectively, this can create a pipeline of under- and mis-reporting. A mental models approach geared towards uncovering implicit biases and attitudes about concussion symptoms and reporting can help open the door towards changing the current culture of resistance around concussion symptom reporting throughout the concussion identification and treatment pipeline.

Finally, in stratified regression analyses, we found that the child's injury history was significantly associated with intentions to seek treatment for higher-risk symptom indices, but not the lower-risk symptom index or averaged intentions to seek treatment. This finding might have important methodological implications for future research. Primarily, without using the CDA defined indices, our understanding of caregivers' mental models would have been insufficient. Future studies should consider symptom-based and data-driven methodological approaches when observing attitudes towards and trends of concussions in adolescents.

Of note, the addition of using injury context in the current survey is novel and can add to the understanding of how caregivers' mental models of concussion symptoms develop. Although no meaningful differences in intention to seek medical treatment across scenarios (accidental fall, fight, and sports) were discovered, the idea that caregivers interpret their child's injury differently depending on the context in which the injury is sustained appears intuitive and may be a contributing factor in caregivers' mental models.

#### 4.2. Limitations and Future Directions

This study had several strengths, including its focus on caregivers' intentions of seeking medical treatment, an early adolescent population, and differences in symptom severity across injury context, but caution should be exercised with generalizing the results of our study to other populations due to our relatively homogenous convenience sample. This study was novel as it presented a data-driven method of examining caregivers' implicit beliefs/mental models. Previous studies have relied on explicit beliefs to inform mental models. This study was intended to serve as a proof of concept of applying the CDA method to analyze implicit beliefs with a goal of elucidating caregivers' mental models of concussions. Future studies should evaluate the development and malleability of these psychological models of concussion and determine how these factors might relate to post injury care and recovery. Future studies should also explore the use of data-driven

techniques, such as CDA, to understand caregivers' mental models in other areas of injury prevention. Finally, larger studies including more child, caregiver, and contextual factors should be conducted to determine the replicability of our results in different, more heterogeneous samples.

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